What is Claimed:

1. A method for manufacturing a quantum electronic device, which includes at least one fine feature on a submicron feature, the at least one fine feature to be located on the submicron feature with a tolerance less than an illumination wavelength used to image the device during manufacture, the method comprising the steps of:

a) providing a quantum electronic device preform including the submicron feature on a top surface;

b) illuminating the top surface of the quantum electronic device preform with light having the illumination wavelength;

c) imaging the top surface of the quantum electronic device preform with a digital camera to produce an alignment image of the top surface which includes a matrix of pixels, the alignment image being scaled such that each pixel has a width corresponding to a constant distance on the top surface of the quantum electronic device preform, the constant distance being less than half of the illumination wavelength;

d) defining an image coordinate system for the top surface of the quantum electronic device preform using the alignment image and the constant distance;

e) determining coordinates of a reference point and an orientation of the submicron feature of the top surface of the quantum electronic device preform in the image coordinate system using the alignment image;

f) determining initial coordinates of a beam spot of a micro-machining laser in the image coordinate system using the alignment image;

g) aligning the beam spot of the micro-machining laser over a portion of the submicron feature of the quantum electronic device preform using the coordinates of the reference point and the orientation of the submicron feature determined in step (e) and the initial coordinates of the beam spot determined in step (f); and

h) machining device material of the quantum electronic device preform with the micro-machining laser to form the at least one fine feature on the submicron feature, completing the quantum electronic device.

2. The method according to claim 1, wherein the quantum electronic device is at least one of a quantum cellular automaton, a coupled quantum dot device, or a resonant tunneling device.

3. The method according to claim 1, wherein step (f) includes the steps of:

f1) ablating a calibration mark in an alignment section of the top surface of the quantum electronic device preform with the micro-machining laser; and

f2) determining a location of a center of the calibration mark in the alignment image;

f3) using the location of the center of the calibration mark in the alignment image and the image coordinate system defined in step (d) to determine the initial coordinates of the beam spot of the micro-machining laser in the image coordinate system.

4. The method according to claim 3, wherein step (d) includes the steps of:

d1) ablating a second calibration mark in the alignment section of the top surface of the quantum electronic device preform with the micro-machining laser, the second calibration mark located such that centers of the two calibration marks are a predetermined distance apart;

d2) determining the constant distance based on a number of pixels between the centers of the two calibration marks in the alignment image; and

d3) using locations of the two calibration marks in the alignment image and the constant distance determined in step (d2) to define the image coordinate system for the top surface of the quantum electronic device preform.

5. The method according to claim 3, wherein:

the constant distance is a predetermined distance; and

step (d) includes using the location of the center of the calibration mark in the alignment image, the matrix of pixels, and the constant distance to define the image coordinate system for the top surface of the quantum electronic device preform.

6. The method according to claim 3, wherein:

the quantum electronic device preform includes two reference marks, located such that the two reference marks have respective centers that are a predetermined distance apart; and

step (d) includes the steps of;

d1) determining the constant distance based on a number of pixels between the centers of the two reference marks in the alignment image; and

d2) using the location of the center of the calibration mark in the alignment image determined in step (f2) and the constant distance determined in step (d1) to define the image coordinate system for the top surface of the quantum electronic device preform.

7. The method according to claim 3, wherein:

the submicron feature of the quantum electronic device preform is formed of the device material, which has a device machining threshold;

the alignment section of the top surface of the quantum electronic device preform is coated with a coating material having a coating ablation threshold, the coating ablation threshold being less than the device machining threshold;

step (f1) includes operating the micro-machining laser with an alignment peak fluence to ablate the calibration mark in only the coating material of the alignment section, the alignment peak fluence being less than the device machining threshold and greater than the coating ablation threshold; and

step (h) includes operating the micro-machining laser with a machining peak fluence to machine the at least one fine feature in the device material of the submicron feature, the machining peak fluence being greater than the device machining threshold.

8. The method according to claim 1, wherein:

a light beam of the micro-machining laser propagates along a beam path including;

a transversely moveable pinhole mask having a pinhole located in the beam path; and

reducing optics to produce the beam spot on the top surface of the quantum electronic device preform having a beam spot diameter smaller than a pinhole diameter of the pinhole; and

step (g) includes aligning the beam spot of the micro-machining laser over the portion of the submicron feature of the quantum electronic device preform by moving the transversely moveable pinhole mask a scaled amount based on a ratio of the pinhole diameter to the beam spot diameter.

9. The method according to claim 1, wherein step (g) includes aligning the beam spot of the micro-machining laser over the portion of the submicron feature of the quantum electronic device preform by moving the quantum electronic device preform.

10. The method according to claim 1, wherein the micro-machining laser is one of an ultrafast laser or an excimer laser.

11. The method according to claim 1, wherein:

the micro-machining laser is an ultrafast laser;

a full width at half maximum (FWHM) of the beam spot of the micro-machining laser on the top surface is diffraction limited; and

step (h) includes operating the micro-machining laser with a machining fluence to machine the at least one fine feature in the device material of the submicron feature, the machining fluence being such that a diameter of an area of the top surface machined by a pulse of the ultrafast laser is less than the FWHM of the beam spot.

12. The method according to claim 1, wherein machining the device material in step (h) includes one of ablating the device material or permanently altering a structure of the device material.

13. A method for manufacturing a micro-optical device, which includes at least one fine feature on a submicron feature, the at least one fine feature to be located on the submicron feature with a tolerance less than an illumination wavelength used to image the device during manufacture, the method comprising the steps of:

a) providing a micro-optical device preform including the submicron feature on a top surface;

b) illuminating the top surface of the micro-optical device preform with light having the illumination wavelength;

c) imaging the top surface of the micro-optical device preform with a digital camera to produce an alignment image of the top surface which includes a matrix of pixels, the alignment image being scaled such that each pixel has a width corresponding to

a constant distance on the top surface of the micro-optical device preform, the constant distance being less than half of the illumination wavelength;

d) defining an image coordinate system for the top surface of the micro-optical device preform using the alignment image and the constant distance;

e) determining coordinates of a reference point and an orientation of the submicron feature of the top surface of the micro-optical device preform in the image coordinate system using the alignment image;

f) determining initial coordinates of a beam spot of a micro-machining laser in the image coordinate system using the alignment image;

g) aligning the beam spot of the micro-machining laser over a portion of the submicron feature of the micro-optical device preform using the coordinates of the reference point and the orientation of the submicron feature determined in step (e) and the initial coordinates of the beam spot determined in step (f); and

h) machining device material of the micro-optical device preform with the micro-machining laser to form the at least one fine feature on the submicron feature, completing the micro-optical device.

14. The method according to claim 13, wherein the micro-optical device is at least one of a multifunction optical array, a diffractive optical element, or a beam shaper.

15. The method according to claim 13, wherein step (f) includes the steps of:

f1) ablating a calibration mark in an alignment section of the top surface of the micro-optical device preform with the micro-machining laser; and

f2) determining a location of a center of the calibration mark in the alignment image;

f3) using the location of the center of the calibration mark in the alignment image and the image coordinate system defined in step (d) to determine the initial coordinates of the beam spot of the micro-machining laser in the image coordinate system.

16. The method according to claim 15, wherein step (d) includes the steps of:

d1) ablating a second calibration mark in the alignment section of the top surface of the micro-optical device preform with the micro-machining laser, the second calibration mark located such that centers of the two calibration marks are a predetermined distance apart;

d2) determining the constant distance based on a number of pixels between the centers of the two calibration marks in the alignment image; and

d3) using locations of the two calibration marks in the alignment image and the constant distance determined in step (d2) to define the image coordinate system for the top surface of the micro-optical device preform.

17. The method according to claim 15, wherein:

the constant distance is a predetermined distance; and

step (d) includes using the location of the center of the calibration mark in the alignment image, the matrix of pixels, and the constant distance to define the image coordinate system for the top surface of the micro-optical device preform.

18. The method according to claim 15, wherein:

the micro-optical device preform includes two reference marks, located such that the two reference marks have respective centers that are a predetermined distance apart; and

step (d) includes the steps of;

d1) determining the constant distance based on a number of pixels between the centers of the two reference marks in the alignment image; and

d2) using the location of the center of the calibration mark in the alignment image determined in step (f2) and the constant distance determined in step (d1) to define the image coordinate system for the top surface of the micro-optical device preform.

19. The method according to claim 15, wherein:

the submicron feature of the micro-optical device preform is formed of the device material, which has a device machining threshold;

the alignment section of the top surface of the micro-optical device preform is coated with a coating material having a coating ablation threshold, the coating ablation threshold being less than the device machining threshold;

step (f1) includes operating the micro-machining laser with an alignment peak fluence to ablate the calibration mark in only the coating material of the alignment section, the alignment peak fluence being less than the device machining threshold and greater than the coating ablation threshold; and

step (h) includes operating the micro-machining laser with a machining peak fluence to machine the at least one fine feature in the device material of the submicron feature, the machining peak fluence being greater than the device machining threshold.

20. The method according to claim 13, wherein:

a light beam of the micro-machining laser propagates along a beam path including;

a transversely moveable pinhole mask having a pinhole located in the beam path; and

reducing optics to produce the beam spot on the top surface of the micro-optical device preform having a beam spot diameter smaller than a pinhole diameter of the pinhole; and

step (g) includes aligning the beam spot of the micro-machining laser over the portion of the submicron feature of the micro-optical device preform by moving the transversely moveable pinhole mask a scaled amount based on a ratio of the pinhole diameter to the beam spot diameter.

21. The method according to claim 13, wherein step (g) includes aligning the beam spot of the micro-machining laser over the portion of the submicron feature of the micro-optical device preform by moving the micro-optical device preform.

22. The method according to claim 13, wherein the micro-machining laser is one of an ultrafast laser or an excimer laser.

23. The method according to claim 13, wherein:

the micro-machining laser is an ultrafast laser;

a full width at half maximum (FWHM) of the beam spot of the micro-machining laser on the top surface is diffraction limited; and

step (h) includes operating the micro-machining laser with a machining fluence to machine the at least one fine feature in the device material of the submicron feature, the machining fluence being such that a diameter of an area of the top surface machined by a pulse of the ultrafast laser is less than the FWHM of the beam spot.

24. The method according to claim 13, wherein machining the device material in step (h) includes one of ablating the device material or permanently altering a structure of the device material.

25. A method for manufacturing a micro-mechanical oscillator, which includes at least one fine feature on a submicron feature, the at least one fine feature to be located on the submicron feature with a tolerance less than an illumination wavelength used to image the device during manufacture, the method comprising the steps of:

a) providing a micro-mechanical oscillator preform including the submicron feature on a top surface;

b) illuminating the top surface of the micro-mechanical oscillator preform with light having the illumination wavelength;

c) imaging the top surface of the micro-mechanical oscillator preform with a digital camera to produce an alignment image of the top surface which includes a matrix of pixels, the alignment image being scaled such that each pixel has a width corresponding to a constant distance on the top surface of the micro-mechanical oscillator preform, the constant distance being less than half of the illumination wavelength;

d) defining an image coordinate system for the top surface of the micro-mechanical oscillator preform using the alignment image and the constant distance;

e) determining coordinates of a reference point and an orientation of the submicron feature of the top surface of the micro-mechanical oscillator in the image coordinate system using the alignment image;

f) determining initial coordinates of a beam spot of a micro-machining laser in the image coordinate system using the alignment image;

g) aligning the beam spot of the micro-machining laser over a portion of the submicron feature of the micro-mechanical oscillator preform using the coordinates of the reference point and the orientation of the submicron feature determined in step (e) and the initial coordinates of the beam spot determined in step (f); and

h) machining device material of the micro-mechanical oscillator preform with the micro-machining laser to form the at least one fine feature on the submicron feature, completing the micro-mechanical oscillator.

26. The method according to claim 25, wherein step (f) includes the steps of:

f1) ablating a calibration mark in an alignment section of the top surface of the micro-mechanical oscillator preform with the micro-machining laser; and

f2) determining a location of a center of the calibration mark in the alignment image;

f3) using the location of the center of the calibration mark in the alignment image and the image coordinate system defined in step (d) to determine the initial coordinates of the beam spot of the micro-machining laser in the image coordinate system.

27. The method according to claim 26, wherein step (d) includes the steps of:

d1) ablating a second calibration mark in the alignment section of the top surface of the micro-mechanical oscillator preform with the micro-machining laser, the second calibration mark located such that centers of the two calibration marks are a predetermined distance apart;

d2) determining the constant distance based on a number of pixels between the centers of the two calibration marks in the alignment image; and

d3) using locations of the two calibration marks in the alignment image and the constant distance determined in step (d2) to define the image coordinate system for the top surface of the micro-mechanical oscillator preform.

28. The method according to claim 26, wherein:

the constant distance is a predetermined distance; and

step (d) includes using the location of the center of the calibration mark in the alignment image, the matrix of pixels, and the constant distance to define the image coordinate system for the top surface of the micro-mechanical oscillator preform.

29. The method according to claim 26, wherein:

the micro-mechanical oscillator preform includes two reference marks, located such that the two reference marks have respective centers that are a predetermined distance apart; and

step (d) includes the steps of;

d1) determining the constant distance based on a number of pixels between the centers of the two reference marks in the alignment image; and

d2) using the location of the center of the calibration mark in the alignment image determined in step (f2) and the constant distance determined in step (d1) to define the image coordinate system for the top surface of the micro-mechanical oscillator preform.

30. The method according to claim 26, wherein:

the submicron feature of the micro-mechanical oscillator preform is formed of the device material, which has a device machining threshold;

the alignment section of the top surface of the micro-mechanical oscillator preform is coated with a coating material having a coating ablation threshold, the coating ablation threshold being less than the device machining threshold;

step (f1) includes operating the micro-machining laser with an alignment peak fluence to ablate the calibration mark in only the coating material of the alignment

section, the alignment peak fluence being less than the device machining threshold and greater than the coating ablation threshold; and

step (h) includes operating the micro-machining laser with a machining peak fluence to machine the at least one fine feature in the device material of the submicron feature, the machining peak fluence being greater than the device machining threshold.

31. The method according to claim 25, wherein:

a light beam of the micro-machining laser propagates along a beam path including;

a transversely moveable pinhole mask having a pinhole located in the beam path; and

reducing optics to produce the beam spot on the top surface of the micro-mechanical oscillator preform having a beam spot diameter smaller than a pinhole diameter of the pinhole; and

step (g) includes aligning the beam spot of the micro-machining laser over the portion of the submicron feature of the micro-mechanical oscillator preform by moving the transversely moveable pinhole mask a scaled amount based on a ratio of the pinhole diameter to the beam spot diameter.

32. The method according to claim 25, wherein step (g) includes aligning the beam spot of the micro-machining laser over the portion of the submicron feature of the micro-mechanical oscillator preform by moving the micro-mechanical oscillator preform.

33. The method according to claim 25, wherein the micro-machining laser is one of an ultrafast laser or an excimer laser.

34. The method according to claim 25, wherein a resonance spectrum of the micro-mechanical oscillator is tuned by the at least one fine feature machined on the submicron feature.

35. The method according to claim 34, wherein:

step (a) includes the steps of;

a1) activating the micro-mechanical oscillator;

a2) determining an initial resonance spectrum of the micro-mechanical oscillator;

a3) comparing the initial resonance spectrum determined in step (a2) to a predetermined resonance spectrum; and

a4) determining a desired shape on the submicron feature of the at least one fine feature based on the comparison in step (a3); and

step (h) includes machining the at least one fine feature to have the desired shape on the submicron feature determined in step (a4) with the micro-machining laser.

36. The method according to claim 25, wherein:

the micro-machining laser is an ultrafast laser;

a full width at half maximum (FWHM) of the beam spot of the micro-machining laser on the top surface is diffraction limited; and

step (h) includes operating the micro-machining laser with a machining fluence to machine the at least one fine feature in the device material of the submicron feature, the machining fluence being such that a diameter of an area of the top surface machined by a pulse of the ultrafast laser is less than the FWHM of the beam spot.

37. The method according to claim 25, wherein machining the device material in step (h) includes one of ablating the device material or permanently altering a structure of the device material.

38. A method for manufacturing a mold for microstructures, which includes at least one fine feature on a submicron feature, the at least one fine feature to be located on the submicron feature with a tolerance less than an illumination wavelength used to image the mold during manufacture, the method comprising the steps of:

a) providing a mold preform including the submicron feature on a top surface;

b) illuminating the top surface of the mold preform with light having the illumination wavelength;

c) imaging the top surface of the mold preform with a digital camera to produce an alignment image of the top surface which includes a matrix of pixels, the alignment image being scaled such that each pixel has a width corresponding to a constant distance on the top surface of the mold preform, the constant distance being less than half of the illumination wavelength;

d) defining an image coordinate system for the top surface of the mold preform using the alignment image and the constant distance;

e) determining coordinates of a reference point and an orientation of the submicron feature of the top surface of the mold preform in the image coordinate system using the alignment image;

f) determining initial coordinates of a beam spot of a micro-machining laser in the image coordinate system using the alignment image;

g) aligning the beam spot of the micro-machining laser over a portion of the submicron feature of the mold preform using the coordinates of the reference point and

the orientation of the submicron feature determined in step (e) and the initial coordinates of the beam spot determined in step (f); and

h) ablating mold material of the mold preform with the micro-machining laser to form the at least one fine feature on the submicron feature, completing the mold.

39. The method according to claim 38, wherein the microstructures to be formed by the mold are at least one of quantum cellular automata, coupled quantum dot devices, resonant tunneling devices, multifunction optical arrays, diffractive optical elements, beam shapers, microlens arrays, optical diffusers, beam splitters, laser diode correctors, fine pitch gratings, photonic crystals, micro-electrical-mechanical systems, micro-circuitry, polymerase chain reaction microsystems, biochips for detection of hazardous chemical and biological agents, high-throughput drug screening and selection microsystems, micro-surface-acoustic-wave devices, or micro-mechanical oscillators.

40. The method according to claim 38, wherein step (f) includes the steps of:

f1) ablating a calibration mark in an alignment section of the top surface of the mold preform with the micro-machining laser; and

f2) determining a location of a center of the calibration mark in the alignment image;

f3) using the location of the center of the calibration mark in the alignment image and the image coordinate system defined in step (d) to determine the initial coordinates of the beam spot of the micro-machining laser in the image coordinate system.

41. The method according to claim 40, wherein step (d) includes the steps of:

d1) ablating a second calibration mark in the alignment section of the top surface of the mold preform with the micro-machining laser, the second calibration mark located such that centers of the two calibration marks are a predetermined distance apart;

d2) determining the constant distance based on a number of pixels between the centers of the two calibration marks in the alignment image; and

d3) using locations of the two calibration marks in the alignment image and the constant distance determined in step (d2) to define the image coordinate system for the top surface of the mold preform.

42. The method according to claim 40, wherein:

the constant distance is a predetermined distance; and

step (d) includes using the location of the center of the calibration mark in the alignment image, the matrix of pixels, and the constant distance to define the image coordinate system for the top surface of the mold preform.

43. The method according to claim 40, wherein:

the mold preform includes two reference marks, located such that the two reference marks have respective centers that are a predetermined distance apart; and

step (d) includes the steps of;

d1) determining the constant distance based on a number of pixels between the centers of the two reference marks in the alignment image; and

d2) using the location of the center of the calibration mark in the alignment image determined in step (f2) and the constant distance determined in step (d1) to define the image coordinate system for the top surface of the mold preform.

44. The method according to claim 40, wherein:

the submicron feature of the mold preform is formed of the mold material, which has a mold ablation threshold;

the alignment section of the top surface of the mold preform is coated with a coating material having a coating ablation threshold, the coating ablation threshold being less than the mold ablation threshold;

step (f1) includes operating the micro-machining laser with an alignment peak fluence to ablate the calibration mark in only the coating material of the alignment section, the alignment peak fluence being less than the mold ablation threshold and greater than the coating ablation threshold; and

step (h) includes operating the micro-machining laser with an ablation peak fluence to ablate the at least one fine feature in the mold material of the submicron feature, the ablation peak fluence being greater than the mold ablation threshold.

45. The method according to claim 38, wherein:

a light beam of the micro-machining laser propagates along a beam path including;

a transversely moveable pinhole mask having a pinhole located in the beam path; and

reducing optics to produce the beam spot on the top surface of the mold preform having a beam spot diameter smaller than a pinhole diameter of the pinhole; and

step (g) includes aligning the beam spot of the micro-machining laser over the portion of the submicron feature of the mold preform by moving the transversely moveable pinhole mask a scaled amount based on a ratio of the pinhole diameter to the beam spot diameter.

46. The method according to claim 38, wherein step (g) includes aligning the beam spot of the micro-machining laser over the portion of the submicron feature of the mold preform by moving the mold preform.

47. The method according to claim 38, wherein the micro-machining laser is one of an ultrafast laser or an excimer laser.

48. The method according to claim 38, wherein:

the micro-machining laser is an ultrafast laser;

a full width at half maximum (FWHM) of the beam spot of the micro-machining laser on the top surface is diffraction limited; and

step (h) includes operating the micro-machining laser with an ablation fluence to ablate the at least one fine feature in the mold material of the submicron feature, the ablation fluence being such that a diameter of an area of the top surface ablated by a pulse of the ultrafast laser is less than the FWHM of the beam spot.

49. A method for forming a defect in a photonic crystal, the method comprising the steps of:

a) providing a photonic crystal work piece having a top surface including;

an alignment section; and

a photonic crystal section formed of a plurality of air holes in an interstitial material, each air hole having a diameter less than an illumination wavelength used to image the work piece during defect formation and centers of two of the plurality of air holes being a predetermined distance apart;

b) ablating an origin mark in the alignment section of the photonic crystal work piece with a micro-machining laser;

c) illuminating the top surface of the photonic crystal work piece with light having the illumination wavelength;

d) imaging the top surface of the photonic crystal work piece with a digital camera to produce an alignment image of the top surface which includes a matrix of pixels, the alignment image being scaled such that each pixel has a width corresponding to a constant distance on the top surface of the photonic crystal work piece, the constant distance being less than half of the illumination wavelength;

e) determining the constant distance based on a number of pixels in the alignment image between the centers of the two air holes that are separated by the predetermined distance;

f) determining a location of a center of the calibration mark in the alignment image and defining an image coordinate system for the top surface of the photonic crystal work piece using the location of the origin mark in the alignment image, the matrix of pixels, and the constant distance determined in step (e);

g) determining coordinates of centers of the plurality of air holes of the photonic crystal section of the top surface of the photonic crystal work piece in the image coordinate system using the alignment image;

h) determining initial coordinates of a beam spot of the micro-machining laser in the image coordinate system using the location of the origin mark in the alignment image;

i) aligning the beam spot of the micro-machining laser over a defect location of the photonic crystal section using the coordinates of the air holes determined in step (g) and the initial coordinates of the beam spot determined in step (h); and

j) machining interstitial material at the defect location of the photonic crystal section with the micro-machining laser to form the defect.

50. The method according to claim 49, wherein:

the interstitial material has a work piece machining threshold;

the alignment section of the top surface of the photonic crystal work piece is coated with a coating material having a coating ablation threshold, the coating ablation threshold being less than the work piece machining threshold;

step (b) operating the micro-machining laser with an alignment peak fluence to ablate the origin mark in only the coating material of the alignment section, the alignment peak fluence being less than the work piece machining threshold and greater than the coating ablation threshold; and

step (j) includes operating the micro-machining laser with a machining peak fluence to machine the interstitial material at the defect location, the machining peak fluence being greater than the work piece machining threshold.

51. The method according to claim 49, wherein:

a light beam of the micro-machining laser propagates along a beam path including;

a transversely moveable pinhole mask having a pinhole located in the beam path; and

reducing optics to produce the beam spot on the top surface of the photonic crystal work piece having a beam spot diameter smaller than a pinhole diameter of the pinhole; and

step (i) includes aligning the beam spot of the micro-machining laser over the defect location of the photonic crystal section of the photonic crystal work piece by moving the transversely moveable pinhole mask a scaled amount based on a ratio of the pinhole diameter to the beam spot diameter.

52. The method according to claim 49, wherein step (i) includes aligning the beam spot of the micro-machining laser over the defect location of the photonic crystal section of the photonic crystal work piece by moving the photonic crystal work piece.

53. The method according to claim 49, wherein the micro-machining laser is one of an ultrafast laser or an excimer laser.

54. The method according to claim 49, wherein a transmission spectrum of the photonic crystal is tuned by the defect formed in step (j).

55. The method according to claim 54, wherein:

step (a) includes the steps of;

a1) determining the transmission spectrum of the photonic crystal;

a2) comparing the transmission spectrum determined in step (a1) to a predetermined transmission spectrum; and

a3) determining a shape of the defect and the defect location based on the comparison in step (a2); and

step (j) includes forming the defect at the defect location and having the shape determined in step (a3).

56. The method according to claim 49, wherein:

the micro-machining laser is an ultrafast laser;

a full width at half maximum (FWHM) of the beam spot of the micro-machining laser on the top surface is diffraction limited; and

step (j) includes operating the micro-machining laser with a machining fluence to machine the at least one fine feature in the interstitial material of the photonic crystal work piece, the machining fluence being such that a diameter of an area of the top surface machined by a pulse of the ultrafast laser is less than the FWHM of the beam spot.

57. The method according to claim 49, wherein machining the interstitial material in step (j) includes one of ablating the interstitial material or permanently altering a refractive index of the interstitial material.

58. A method for mass customizing a plurality of microstructures with a laser micro-machining system, each microstructure having at least one of a plurality of customization features, the method comprising the steps of:

a) providing a plurality of microstructure preforms, each microstructure preform including a top surface and a submicron feature on the top surface;

b) selecting a microstructure preform from the plurality of microstructure preforms and at least one customization feature from the plurality of customization features, the at least one customization feature to be located on the submicron feature with a tolerance less than an illumination wavelength used to image the microstructures during customization;

c) coarsely aligning the selected microstructure preform in the laser micro-machining system;

d) illuminating the top surface of the selected microstructure preform with light having the illumination wavelength;

e) imaging the top surface of the selected microstructure preform with a digital camera to produce an alignment image of the top surface which includes a matrix of pixels, the alignment image being scaled such that each pixel has a width corresponding to a constant distance on the top surface of the selected microstructure preform, the constant distance being less than half of the illumination wavelength;

f) defining an image coordinate system for the top surface of the selected microstructure preform using the alignment image and the constant distance;

g) determining coordinates of a reference point and an orientation of the submicron feature of the top surface of the selected microstructure preform in the image coordinate system using the alignment image;

h) determining initial coordinates of a beam spot of the laser micro-machining system in the image coordinate system using the alignment image;

i) aligning the beam spot of the laser micro-machining system over a portion of the submicron feature of the selected microstructure preform using the coordinates of the reference point and the orientation of the submicron feature determined in step (g), the initial coordinates of the beam spot determined in step (h), and the at least one customization feature selected in step (b);

j) machining device material of the selected microstructure preform with the laser micro-machining system to form the at least one customization feature selected in step (b) on the submicron feature of the selected microstructure preform to form a customized microstructure; and

k) repeating steps (b), (c), (d), (e), (f), (g), (h), (i), and (j) for each of the plurality of microstructure preforms provided in step (a).

59. The method according to claim 58, wherein the plurality of microstructures to be mass customized are at least one of microstructure molds, quantum cellular automata, coupled quantum dot devices, resonant tunneling devices, multifunction optical arrays, diffractive optical elements, beam shapers, microlens arrays, optical diffusers, beam splitters, laser diode correctors, fine pitch gratings, photonic crystals, micro-electrical-mechanical systems, micro-circuitry, micro-surface-acoustic-wave devices, or micro-mechanical oscillators.

60. The method according to claim 58, wherein step (h) includes the steps of:

h1) ablating a calibration mark in an alignment section of the top surface of the selected microstructure preform with the micro-machining laser; and

h2) determining a location of a center of the calibration mark in the alignment image;

h3) using the location of the center of the calibration mark in the alignment image and the image coordinate system defined in step (f) to determine the initial coordinates of the beam spot of the laser micro-machining system in the image coordinate system.

61. The method according to claim 60, wherein step (f) includes the steps of:

f1) ablating a second calibration mark in the alignment section of the top surface of the selected microstructure preform with the micro-machining laser, the second calibration mark located such that centers of the two calibration marks are a predetermined distance apart;

f2) determining the constant distance based on a number of pixels between the centers of the two calibration marks in the alignment image; and

f3) using locations of the two calibration marks in the alignment image and the constant distance determined in step (f2) to define the image coordinate system for the top surface of the selected microstructure preform.

62. The method according to claim 60, wherein:

the constant distance is a predetermined distance; and

step (f) includes using the location of the center of the calibration mark in the alignment image, the matrix of pixels, and the constant distance to define the image coordinate system for the top surface of the selected microstructure preform.

63. The method according to claim 60, wherein:

the selected microstructure preform includes two reference marks, located such that the two reference marks have respective centers that are a predetermined distance apart; and

step (f) includes the steps of;

f1) determining the constant distance based on a number of pixels between the centers of the two reference marks in the alignment image; and

f2) using the location of the center of the calibration mark in the alignment image determined in step (h2) and the constant distance determined in step (f1) to define the image coordinate system for the top surface of the selected microstructure preform.

64. The method according to claim 60, wherein:

the submicron features of the plurality of microstructure preforms are formed of the device material, which has a device machining threshold;

the alignment sections of the top surfaces of the plurality of microstructure preforms are coated with a coating material having a coating ablation threshold, the coating ablation threshold being less than the device machining threshold;

step (h1) includes operating the micro-machining laser with an alignment peak fluence to ablate the calibration mark in only the coating material of the alignment section, the alignment peak fluence being less than the device machining threshold and greater than the coating ablation threshold; and

step (j) includes operating the micro-machining laser with a machining peak fluence to machine the at least one fine feature selected in step (b) in the device material of the submicron feature of the selected microstructure preform, the machining peak fluence being greater than the device machining threshold.

65. The method according to claim 58, wherein:

a light beam of the micro-machining laser propagates along a beam path including;

a transversely moveable pinhole mask having a pinhole located in the beam path; and

reducing optics to produce the beam spot on the top surface of the selected microstructure preform having a beam spot diameter smaller than a pinhole diameter of the pinhole; and

step (i) includes aligning the beam spot of the laser micro-machining system over the portion of the submicron feature of the selected microstructure preform by moving the transversely moveable pinhole mask a scaled amount based on a ratio of the pinhole diameter to the beam spot diameter.

66. The method according to claim 58, wherein step (i) includes aligning the beam spot of the laser micro-machining system over the portion of the submicron feature of the selected microstructure preform by moving the selected microstructure preform.

67. The method according to claim 58, wherein a micro-machining laser of the laser micro-machining system is one of an ultrafast laser or an excimer laser.

68. The method according to claim 58, wherein:

a micro-machining laser of the laser micro-machining system is an ultrafast laser;

a full width at half maximum (FWHM) of the beam spot of the micro-machining laser on the top surface is diffraction limited; and

step (j) includes operating the micro-machining laser with a machining fluence to machine the at least one fine feature in the device material of the submicron feature, the machining fluence being such that a diameter of an area of the top surface machined by a pulse of the ultrafast laser is less than the FWHM of the beam spot.

69. The method according to claim 58, wherein machining the device material in step (j) includes one of ablating the device material or permanently altering a structure of the device material.

70. A method for repairing a microstructure with a laser micro-machining system, the microstructure including a submicron defect on a top surface, such that machining of the submicron defect is performed with an accuracy of less than an illumination wavelength used to image the microstructure during repair, the method comprising the steps of:

a) coupling the defective microstructure to a repair mount, the repair mount including an alignment surface adjacent to the defective microstructure;

b) coarsely aligning the repair mount in the laser micro-machining system, such that a beam spot of a micro-machining laser of the laser micro-machining system is incident on the alignment surface of the repair mount;

c) ablating a calibration mark in the alignment surface of repair mount with the micro-machining laser;

d) illuminating the top surface of the defective microstructure and the alignment surface of the repair mount with light having the illumination wavelength;

e) imaging the top surface of the defective microstructure and the alignment surface of the repair mount with a digital camera to produce an alignment image of the top surface which includes a matrix of pixels, the alignment image being scaled such that each pixel has a width corresponding to a constant distance on the imaged surfaces, the constant distance being less than half of the illumination wavelength;

f) determining a location of a center of the calibration mark in the alignment image and defining an image coordinate system for the imaged surfaces using the alignment image, the location of the center of the calibration mark in the alignment image, and the constant distance;

g) determining coordinates of the submicron defect of the top surface of the defective microstructure in the image coordinate system using the alignment image;

h) using the location of the center of the calibration mark in the alignment image and the image coordinate system defined in step (f) to determine initial coordinates of the beam spot of the micro-machining laser in the image coordinate system;

i) aligning the beam spot of the micro-machining laser over a portion of the submicron defect of the defective microstructure using the coordinates of the submicron defect determined in step (g) and the initial coordinates of the beam spot determined in step (h); and

j) machining device material of the defective microstructure with the micro-machining laser to repair the submicron defect of the defective microstructure.

71. The method according to claim 70, wherein the microstructure to be repaired includes at least one of a microstructure mold, a quantum cellular automaton, a coupled quantum dot device, a resonant tunneling device, a multifunction optical array, a diffractive optical element, a beam shaper, a microlens array, an optical diffuser, a beam splitter, a laser diode corrector, a fine pitch grating, a photonic crystal, a micro-electrical-mechanical system, micro-circuitry, a micro-surface-acoustic-wave device, a micro-mechanical oscillator, a polymerase chain reaction microsystem, a biochip for detection of hazardous chemical and biological agents, or a high-throughput drug screening and selection microsystem.

72. The method according to claim 70, wherein step (f) includes the steps of:

f1) ablating a second calibration mark in the alignment surface of the repair mount with the micro-machining laser, the second calibration mark located such that centers of the two calibration marks are a predetermined distance apart;

f2) determining a location of a center of the second calibration mark in the alignment image;

f3) determining the constant distance based on a number of pixels between the centers of the two calibration marks in the alignment image; and

f4) using the locations of the centers of the two calibration marks in the alignment image and the constant distance determined in step (f3) to define the image coordinate system for the imaged surfaces.

73. The method according to claim 70, wherein:

the constant distance is a predetermined distance; and

step (f) includes using the location of the center of the calibration mark in the alignment image, the matrix of pixels, and the constant distance to define the image coordinate system for the imaged surfaces.

74. The method according to claim 70, wherein:

the defective microstructure includes two reference marks, located such that the two reference marks have respective centers that are a predetermined distance apart; and

step (f) includes the steps of;

f1) determining the constant distance based on a number of pixels between the centers of the two reference marks in the alignment image; and

f2) using the location of the center of the calibration mark in the alignment image and the constant distance determined in step (f1) to define the image coordinate system for the imaged surfaces.

75. The method according to claim 70, wherein:

the submicron defect of the defective microstructure is formed of the device material, which has a device machining threshold;

the alignment surface of the repair mount is formed of an alignment material having an alignment ablation threshold, the alignment ablation threshold being less than the device machining threshold;

step (c) includes operating the micro-machining laser with an alignment peak fluence to ablate the calibration mark in the alignment material of the alignment surface, the alignment peak fluence being less than the device machining threshold and greater than the alignment ablation threshold; and

step (j) includes operating the micro-machining laser with a repair peak fluence to repair the submicron defect in the device material of the defective microstructure, the repair peak fluence being greater than the device machining threshold.

76. The method according to claim 70, wherein:

a light beam of the micro-machining laser propagates along a beam path including;

a transversely moveable pinhole mask having a pinhole located in the beam path; and

reducing optics to produce the beam spot on the top surface of the defective microstructure and the alignment surface of the repair mount having a beam spot diameter smaller than a pinhole diameter of the pinhole; and

step (i) includes aligning the beam spot of the micro-machining laser over the portion of the submicron defect of the defective microstructure by moving the transversely moveable pinhole mask a scaled amount based on a ratio of the pinhole diameter to the beam spot diameter.

77. The method according to claim 70, wherein step (i) includes aligning the beam spot of the micro-machining laser over the portion of the submicron defect of the defective microstructure by moving the repair mount.

78. The method according to claim 70, wherein the micro-machining laser is one of an ultrafast laser or an excimer laser.

79. The method according to claim 70, wherein:

the microstructure to be repaired includes micro-circuitry; and

the submicron defect is a short circuit.

80. The method according to claim 70, wherein:

the micro-machining laser is an ultrafast laser;

a full width at half maximum (FWHM) of the beam spot of the micro-machining laser on the top surface is diffraction limited; and

step (j) includes operating the micro-machining laser with a machining fluence to machine the device material of the submicron defect, the machining fluence being such that a diameter of an area of the top surface machined by a pulse of the ultrafast laser is less than the FWHM of the beam spot.

81. The method according to claim 70, wherein machining the device material in step (j) includes one of ablating the device material or permanently altering a structure of the device material.

82. A method for pre-calibration of a laser micro-machining system to achieve alignment tolerances greater than a diffraction limit of an illumination wavelength used during pre-calibration for machining of pre-existing microstructures including at least one submicron feature, the method comprising the steps of:

a) mounting an alignment blank in the laser micro-machining system, such that a beam spot of a micro-machining laser of the laser micro-machining system is incident on a top surface of the alignment blank;

b) ablating a first calibration mark and a second calibration mark in the top surface of the alignment blank with the micro-machining laser, the two calibration marks located such that centers of the two calibration marks are a predetermined distance apart;

c) illuminating the top surface of the alignment blank with light having the illumination wavelength;

d) imaging the top surface of the alignment blank with a digital camera to produce an alignment image of the top surface which includes a matrix of pixels, the alignment image being scaled such that each pixel has a width corresponding to a constant distance on the imaged surface, the constant distance being less than half of the illumination wavelength;

e) determining the constant distance based on a number of pixels between the centers of the two calibration marks in the alignment image;

f) determining locations of centers of the two calibration marks in the alignment image and using the locations of the centers of the two calibration marks in the alignment image and the constant distance determined in step (e) to define an image coordinate system for surfaces imaged by the digital camera;

g) using the location of the center of the second calibration mark in the alignment image and the image coordinate system defined in step (f) to determine initial

coordinates of the beam spot of the micro-machining laser in the image coordinate system;

h) removing the alignment blank from the laser micro-machining system; and

i) mounting one of the pre-existing microstructures to be machined in the laser micro-machining system, such that a beam spot of the micro-machining laser is incident on a machining surface of the one pre-existing microstructure.

83. The method according to claim 82, wherein the pre-existing microstructures to be machined include at least one of a microstructure mold, a quantum cellular automaton, a coupled quantum dot device, a resonant tunneling device, a multifunction optical array, a diffractive optical element, a beam shaper, a microlens array, an optical diffuser, a beam splitter, a laser diode corrector, a fine pitch grating, a photonic crystal, a micro-electrical-mechanical system, micro-circuitry, a micro-surface-acoustic-wave device, a micro-mechanical oscillator, a polymerase chain reaction microsystem, a biochip for detection of hazardous chemical and biological agents, or a high-throughput drug screening and selection microsystem.

84. The method according to claim 82, wherein a light beam of the micro-machining laser propagates along a beam path including:

a transversely moveable pinhole mask having a pinhole located in the beam path; and

reducing optics to produce the beam spot on the surfaces imaged by the digital camera having a beam spot diameter smaller than a pinhole diameter of the pinhole.

85. The method according to claim 82, wherein the micro-machining laser is one of an ultrafast laser or an excimer laser.